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(54) **Condition monitoring equipment for power output devices**

(57) Power output devices such as thrusters, hydraulic rams, motor/gearbox combinations, and valve actuators are used in situations where the highest reliability is mandatory.

Condition Monitoring Equipment 5 uses a suitable transducer 6 to measure the output of such an output Device 1 in response to a command input at 2. This measurement is repeated at frequent intervals during the execution of the command, and from this series of measurements various parameters indicative of performance are calculated.

The equipment 5 may contain a model of the device 1, perhaps including the load 4 and associated control system (10), which in conjunction with the command (measured by a second transducer 7) is used to calculate the expected system response. From this calculated response is derived a set of target parameters, which are compared with the measured parameters.

By comparisons between the measured parameters and the target parameters, any malfunction or deterioration of performance can be detected, and displayed remotely 8 or locally 9.

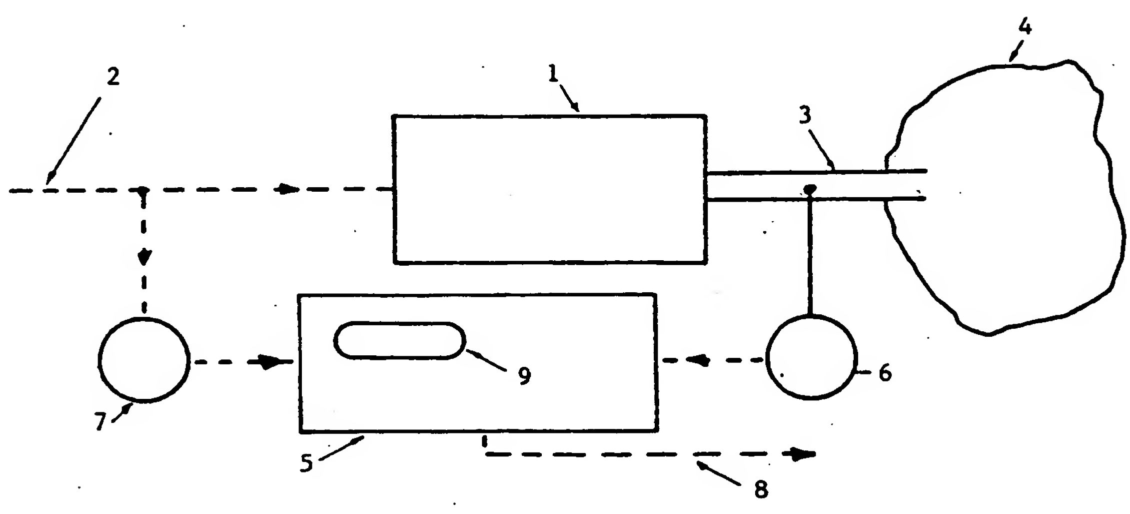

Figure 1

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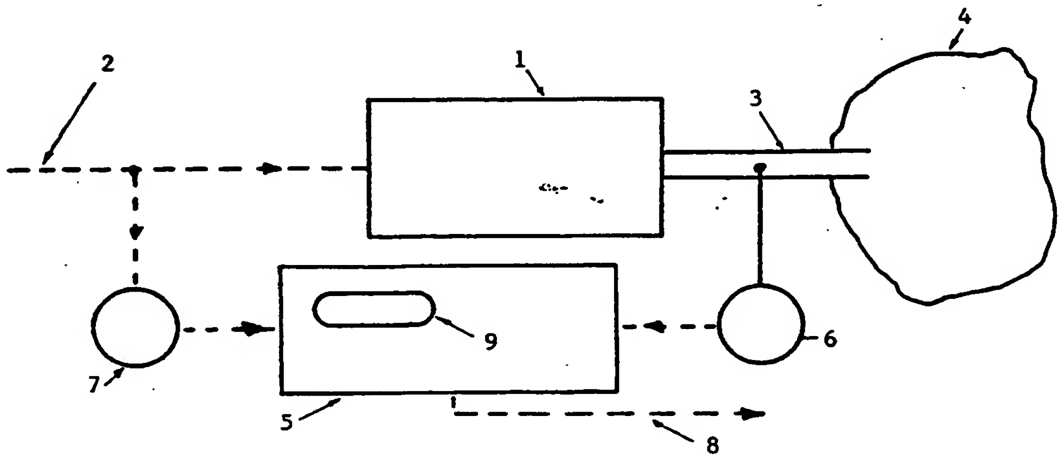

Figure 1

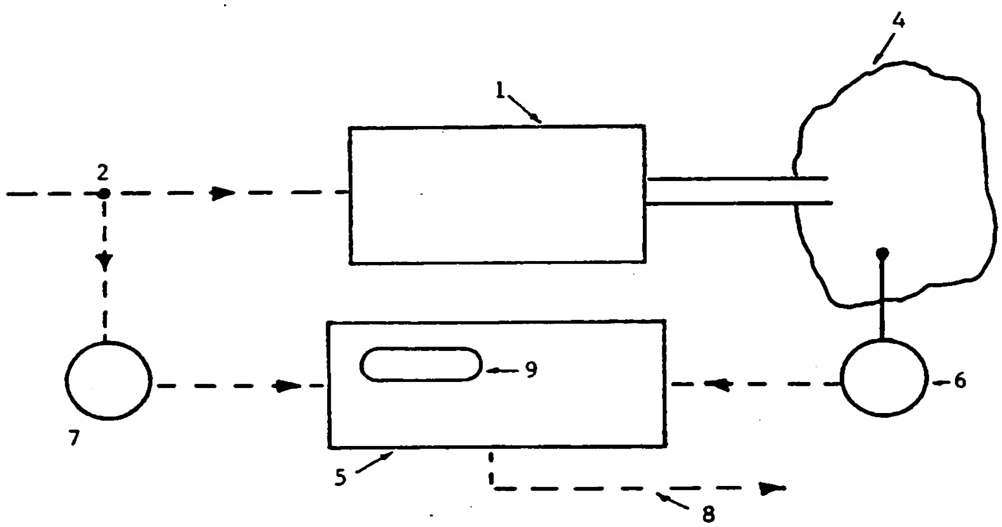

Figure 2

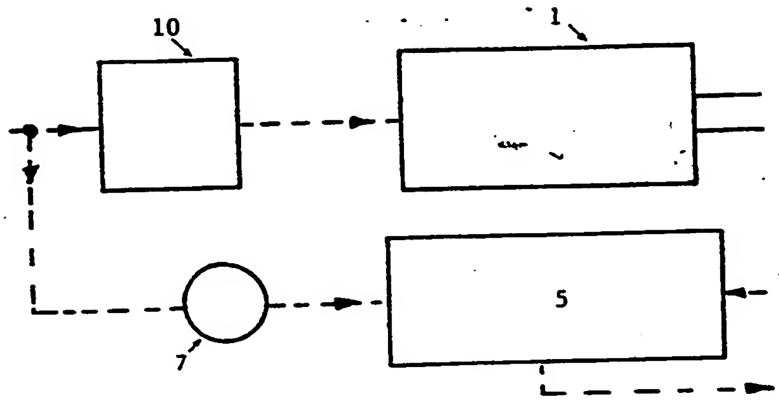

Figure 3

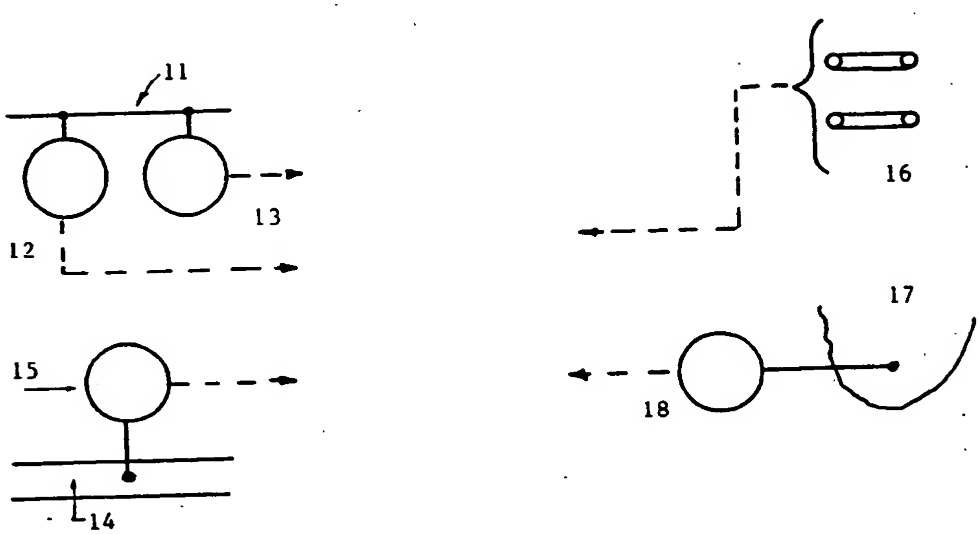

Figure 4

SPECIFICATION

Condition monitoring equipment for power output devices

Mechanical actuators, electromechanical power output devices, thrusters, hydraulic and pneumatic actuators, etc., are frequently used in applications where the highest reliability is mandatory. This condition monitoring equipment analyses and response of the power output device to each command, looking for evidence of deterioration or failure.

The general arrangement is shown in Fig. 1. The response of the device 1 being monitored is measured by means of some suitable transducer 6, (e.g. position, angular position, displacement or movement, according to the particular application), attached to the mechanical output 3. The resultant electrical signal is taken to the condition monitoring equipment 5. All incoming control signals to the mechanical device are copied to the equipment (with buffering to change voltage levels, provide electrical isolation, convert from pneumatic or hydraulic signals to electrical signals, etc. as required). This interfacing is here shown provided by the transducer 7.

When the equipment detects a control signal to the mechanical device, it reacts by measuring the output of this device at frequent intervals, building up a "position profile" which consists of a set of readings of position, (or displacement, or angular position, or some similar parameter), continuing until after the command has been executed and all movement has ceased.

This set of measurement is then analysed, in order to obtain information about the response of the mechanical device to the command. Although the actual analysis may depend on the particular application, it would be normal to deduce from the position profile

1) The dead-time before the mechanical device starts to move.

2) The backlash on changing direction of movement.

3) The steady speed.

4) The over run after the command signal has ended.

5) The smoothness (or irregularity) of motion.

6) The initial acceleration.

7) The time taken to reach a set proportion of rated speed.

8) The overall movement which has taken place in response to the command.

The equipment makes use of, and in general will contain within itself, a model of the actuator and the system to which it is coupled, from which is calculated the expected response to the command received by the power output device, and copied into the equipment, and from this calculated response values of some or all of the parameters listed above.

This model requires stored information from the last command, or last few comands, such as the direction of and magnitude of the last movement. (This information is held in a store, generally within the equipment.)

The measured parameters are compared with those calculated from the command signal and the model, and used to generate a "Figure of Merit" which is a measure of the closeness with which the real system complies with the model held within the performance monitoring equipment. The actual parameter weighting of this figure of merit will depend upon the particular properties of the system to be scrutinised.

Local displays 9 will give an indication of changes in various parameters, and some or all of these parameters may also be displayed remotely, possibly on some central data logging or alarm system 8.

Essentially, this "Figure of Merit" is to be used to classify the response of the actuator as

1) Normal

2) Showing signs of deterioration

3) Definite Malfunction

but more detailed classification of the results may be desirable in certain instances.

Several alternative configurations are possible: Fig. 2 shows that the movement of the system in response to a command to the actuator does not of necessity have to be measured at the point where the power is transmitted to the mechanical part of the system, but can be measured at some remote point.

Fig. 3 shows an application in which an electronic controller or signal decoding device 10 is included within the system under scrutiny. The model stored within the equipment is in this instance modified to describe the combined response of the control device, the actuator itself, and the mechanical system to which it is coupled. This is primarily to enable the control or signal decoding device to be included within the parts of the system to be verified by this condition monitoring equipment.

Fig. 4 shows additional transducers which may be necessary for particular applications. If the actuating device is electrically powered, and fluctuations in supply (i.e. voltage and frequency) are to be expected, then the model must be enlarged to take into account these fluctuations, which must be measured by an additional voltage transducer 12 and frequency transducer 13 shown connected t the power supply 11. Similarly, if the actuating device is pneumatically or hydraulically powered, then it may b necessary to measure the pr ssure of the fluid supply 14 by means of a pressure transducer 15.

Vari us additional switches or switch d inputs 16 may be necessary to take into ac-

count changes in operating conditions, etc.

Where the system response is determined by any additional parameters, not already taken into account, then additional transducers 18 may be required to measure these parameters. For the purposes of this example these are shown schematically as originating in the mechanical part of the system 17.

In each of these cases the model which simulates the system response must be modifi d to take into account the effect of these additional inputs.

The condition monitoring equipment may be extended to validate the incoming commands to the system under scrutiny, for instance by comparing the duration and nature of these commands, and the intervals between commands, with preset limits contained within the equipment. The equipment may also be used t detect improper or undesirable movements of the mechanical output when no command signal occurs, or in the interval between commands.

The equipment will contain a "watch-dog" device, so that the equipment is to a very large extent self-checking. That is to say, any fault occuring within the equipment will be detected by the "watch-dog" device, and will generate an external error signal.

The model describing the response of the power output device and mechanical system to a command may be derived empirically, from observations of the response of a known good device to a series of commands, measured 'in situ', or it may be derived from separate performance tests carried out in a test rig or similar facility.

In the former case, the responses of the observed device will be taken as the standard against which performance is compared.

In the latter case the testing of new systems would generally, although not essentially, be carried out by separate equipment, which would generate the parameters to be used by the model in the monitoring equipment. (This method has certain advantages, in that (as an example) it may be easier to generate abnormal supply voltages, loads and conditions in a separate test facility than in the normal operating environment.)

These parameters may be entered into the equipment in any one of a number of ways familiar to those skilled in the applications of modern electronic devices. Obvious methods include manually entering data via a keyboard, (permanent or attached nly for the purpos s of data entry), or storing data on memory devices, which are pr grammed in a separate test device, and then inserted into the equipment itself. Other methods of data transfer could include data links, discs and data tapes.

CLAIMS

1. This equipment makes a frequently repeated series of output position measurements during the period of execution of a command, and by examination of these measurements extracts information relevant to the condition of the system. This information is to include such values as total movement in response to a command, stead state speed, backlash on reversal overshoot or over-run, and smoothness of movement. It is envisaged that for new applications other (additional) parameters may be found which will be of particular value in particular circumstances, and not all of the parameters listed may be required in every application.

2. This equipment as claimed in claim 1 is particularly attractive in situations where any measurements are likely to be degraded by noise, or by the the limited resolution and linearity of commercially available transducers, or by quantisation error, or when the movement of the output is in itself a small part of the permissible range of travel.

This is particularly like to be the case when monitoring the movement of control elements during steady state conditions, in a variety of applications.

Not only does the multiplicity of measurements reduce the effect of non systematic error, but by using statistical or predictive algorithms it is possible extract the maximum information content from such degraded signals.

3. The equipment as claimed in claim 1 and in claim 2 embodies a model of the system, which calculates the response of the system to a measured command, and from this calculated response derives the parameters particularly relevant to the condition of the system. The model is particularly valuable in that it may take into account permitted changes such as fluctuations in power supply conditions and can be extended as necessary to take into account other quantities influencing the response of the system, such as variations in mechanical load, provided only that it is possible to measure these quantities, and relate them deterministically to their effect upon system response.

4. The equipment as claimed in claim 1, claim 2 and in claim 3 carries out a comparison between the parameter derived from the internally held model and the series of measurements and the results of this comparison is used to quantify the "merit" of the system, in terms of the closeness of the correspondence between the measured and calculated parameters. This figure of merit takes into account all information extracted from the system, and can be weighted to take the greatest account of parameters found experimentally to the most closely related t device deterioration, in a particular application.

5. The equipment as claimed in any preceding claim uses a model or simulati n of th system to be monitored. This model may be empirical, based upon a multiplicity of observations, or mathematical, based upon a theo-

retical understanding of the system to be modelled, or any combination of these two cases. In this way, it is possible to extend the usefulness of this equipment to cover a plurality of diverse applications.

6. The equipment as claimed in any preceding claim uses a method of analysis of information gathered using only simple transducers, likely to be both highly reliable and of relatively low cost, and will permit machinery condition monitoring to be extended into fields where methods currently available are inadequate, either because of high transducer and equipment costs, or because the power levels are insufficiently great for reliable measurement to be possible in a working environment, or because methods currently available do not yield sufficient information.

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